## DESIGN OF PROTON LABORATORY 3-WAY

## SPLIT AT 500 GeV IN ENCLOSURE "H"

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The design of the 3-way split has a long history and many participants. The original concept, including a sketch of a 3-way splitting magnet, was published by Andrews et. al.[1] Proton Department work on a detailed design involved two steps: first, the design of a three-way splitting magnet with a 2 3/4" plate separating the East and West channels which left the rest of the geometry of Enclosure "H" intact and the design of new vertical bending magnets with a 5" good field region so as to accomodate the three beams; secondly, an attempt simultaneously to upgrade the West line in Enclosure "H" to 500 GeV and to minimize the thickness of the center plate.

The final 500 GeV system requires construction of four identical 3-way splitting magnets with a 2 1/8" plate separating the East and West channels (and one spare), six wide-gap modified B1 magnets for the vertical bends (and one spare), the addition of two EPB dipoles (one in the West line, and one in the East), a horizonal trim at the end of Enclosure "E" to achieve a Westward displacement of the Enclosure "H" lines of 0.3 mr and complete rearrangement of the dipoles in Enclosure "H".

Other Options

Two other options were thoroughly explored and discarded.  The

first involved building five non-identical 3-way split magnets, each

built of the same laminations but with differing offsets of the mag-

netic channels from the zero-field hole in the center plate.  The

East-West vertical beam separation would have been 2-5/8".  The com-

plication of many different assemblies and the fact that spares would

have to be assembled on the spur of the moment in case of failure

(economic necessity precluding the assembly of five spares) out-

weighed the reduction of the required electrostatic split.  The second

option discarded required building three identical 3-way splitting

magnets with 3" East-West vertical separation and also three "C"

magnets made out of the same laminations with one end cut off.  Again,

the disadvantage of two styles of magnets and the problems of spares

seemed to outweigh the reduction of the required splitting from

3¼" to 3".

Three-Way Splitting Magnet

The dimensions and properties of the 3-way splitting magnet are

shown in Table 1.  Three factors allowed the reduction of the plate

thickness from 2-3/4" to 2-1/8".  First, the 3-way bend angle has been

reduced from 6 mrad to 5 mrad.  Secondly, the coil separation has been

narrowed with subsequent shrinkage of the good-field region.  However,

careful attention has been paid to the question of what is a tolerable

field deviation by concentrating on the average dB/B (averaged over the

curved trajectory through a four-magnet string) and calculating the

effects of the deviation on a phase space boundary.  Figure 1 shows

the average dB/B as a function of horizontal position for three

vertical positions in the magnet string.  Figure 2 shows the distortion

of a large horizontal beam ellipse ($\varepsilon_H = 0.5$ $\pi$ mn -mr) caused by the

worst plane in the magnet, y = 1.125" (near the top pole piece) where

there are very few protons.  The distortion adds less than 10% to the

phase space area.  Thirdly, the additional EPB dipoles in the East

and West legs make up for the reduction in the 3-way bend angle and

reduce the current in the West bend to 1640 amps at 500 GeV.  Table II

lists all the power requirements.

Rearrangement of Enclosure "H"

Enclosure "H" is rearranged in the following way.  (See Fig. 3 and

Table III.)  The West line is packed with EPB dipoles from the SWIC

at the end of the enclosure back to 200' from the front wall.  The

East and Center EPB dipole chains are interchanged in their position

along the beam; specifically, the four East dipoles lie side by side

with the first four West dipoles, leaving a gap of 1.7" for the P-Center

beam (steel-to-steel). A special beam pipe for P-Center is needed

for about 30' and special hanger bolts are needed for the first East

and West EPB dipoles (see Fig. 4).

The extra 0.3 mr bend at the end of Enclosure "E" is necessary

in order that the P-West beam leave Enclosure "H" within the aperture

of the fixed 12" pipe.  The interchange of the East and Center dipoles

is then necessary in order to retain the correct positions of the

East and Center beams in the 12" pipes at the end of Enclosure "H".

With this deflection, the three beams enter Enclosure "H" 3" west of

the center of the 12" pipe from Enclosure "E". The beams leave "H"
with the following offsets (from the 12" exit pipes): P-West beam:
2.7" east; P-Center beam: 2.0" west; P-East beam: 2.5" east.

## Electrostatic Septa Required

Although the magnetic channel of the 3-way splitting magnet is 1.24"
high, the field non-uniformity near the top pole piece is consid-
erably worse than at the center plate, so we intend to center the
beam in the lower 1-1/8" of the West magnetic channel (and upper
1-1/8" of the East channel), which requires $3\frac{1}{4}$" vertical separation
of the East and West beams. The distance from the center of the
Lambertsons to the center of the electrostatic septa is 300 meters.
The wire-cathode separation is assumed to be 2 cm.

The voltage is assumed to be either 70 kV (present operating
limit) or 100 kV (a possible goal of the septum development program).
The number of septa necessary for a three-way split must obviously
be an even integer. Ignoring this quantization, the required number
of septa at the two voltages is as follows:

> 5.1 septa at 100 kV at 500 GeV;
>
> 4.1 septa at 100 kV at 400 GeV;
>
> 7.3 septa at 70 kV at 500 GeV;
>
> 5.8 septa at 70 kV at 400 GeV;

The calculation included an empirical correction factor of 0.88
resulting from beam convergence.

However, if the vertical beam size remains at its present value
(18mm full width at base), the required vertical separation of the
East and West beams can be reduced to 2.85" with an increase in beam

scraping by about a factor of 2 (the tail is not quite flat). This

is the appropriate way to plan to run occasionally at the peak

energy of the machine. The septa requirements at 500 GeV become:

4.5 septa at 100 kV at 500 GeV;

6.4 septa at 70 kV at 500 GeV.

Final choice of the even number of septa necessary will depend

on the ultimate machine energy and the results of the septum devel-

opment program. Rounding off the above numbers suggests that what is

needed is either 6 septa at 70 KV or 4 septa at 100 KV.

Modified B1 Magnets

The EPB dipoles presently used for the vertical bends have

a good field region of 3" in the median plane and 2" at 3/8" off the

median plane. In Enclosure "H", a good field region of 4.6" is re-

quired to accomodate the three beams. Such a magnet was designed

using restamped B1 laminations and booster copper. The properties

of the magnet are given in Table IV and the predicted field map

in Fig. 5. The magnet has the further virtue that the current at

500 GeV is only 1066A. The vertical bending magnets at the end of

Enclosure "E" are also replaced by these modified B1 magnets in

order to keep the two vertical bends as a series dogleg.

Contingency Plans

This system also allows the following possibilities if unfor-

seen difficulties arise. Should the emmitance in the horizontal

plane increase drastically, or should the built magnet have a

much worse field non-uniformity than predicted, the 3-way magnets

can still move 6.0' upstream, providing another 0.6" separation of

the P-West and P-East beams at the first dipoles. New C-magnets
made out of 3-way laminations can be designed instead of adding EPBs.
The fourth 3-way magnet can be removed (if the field is too bad to
accomodate the bending), C-magnets added, and the three beams can
be rotated a bit at the end of "E" (by rotating the electrostatic
septa) so as to put the beams into the good-field region of the
3-way magnets. Further clearance between the first East and West
EPB dipoles can be gained by milling a 1/2" slot in the steel of the
return leg (see Fig. 4).

Beam Monitoring Instrumentation

In the downstream branches, the existing flags and SWICs (one
of each in each line) are relocated as shown in Fig. 3. For the
upstream end of Enclosure "H", four new SWICs have been designed. Be-
fore and after the vertical bending magnets, 6" SWICs (3mm wire spacing)
will display simultaneously profiles of the three beams (SWIC 318
and 319 on Fig. 3). Before and after the 3-way splitting magnets,
special "triple-SWICs" will display each beam separately. Each
element of these triple-SWICs has a sensitive area of 1 1/2" diameter
(1/2mm wire spacing). This will allow simultaneous observation of
widely differing intensity beams.

Acknowledgements

Stan Snowden initially did all the magnet designing and taught
us all the tricks of shimming magnets and using the magnet design
program LINDA. Lee Teng, Helen Edwards, Les Oleksiuk and Gene Fisk
provided occasional advice and criticism. Ed Tilles and Research
Services have carried out the engineering of the magnets.

Reference

1. L. W. Oleksiuk, R. A. Andrews, E. J. Bleser, C. H. Rode, "The NAL Beam Splitting System", IEEE Trans. on Nuclear Science, NS-20, 428 (1973).

| SUBJECT | NAME SCS/CTM/EBT |
|---|---|
| 3-Way Split Magnet (1.24X3X120) | DATE 5/22/74    REVISION DATE |

## MAGNETIC FIELD

| | |
|---|---|
| CENTRAL FIELD | 7.0 kg |
| GOOD FIELD | 2.8"X1.125" |
| FIELD QUALITY | ±.15% |

## POWER:

| | |
|---|---|
| Dc Power | 23.3kW/gap |
| Current | 1100A/gap |
| Voltage | 21.1V/gap |
| Copper Temp. Ave. | |
| Resist @ Temp. | .0192Ω/gap |
| Time Constant | .28sec |
| Inductance | 5.3 mH/gap |

## COOLING:

| | |
|---|---|
| Water Temp. Rise | 11.2 °C |
| Total Flow | 2.6 GPM |
| Pressure | 200 psi |

## COIL DATA:

| | |
|---|---|
| Conductor O.D. | 0.46"X0.46" |
| Hole Diameter | 0.23" |
| Turns | 16/gap |
| Water Paths | 2/gap |
| Ave. Turn Length | 260" |

## WEIGHTS: (est.)

| | |
|---|---|
| Coil & Insul. | 445 lb |
| Core | 6250 lb |
| Support | 200 lb |
| Total Magnet Assembly | 6900 lb |

## CALCULATION CONSTANTS:

$B_{kg} =$

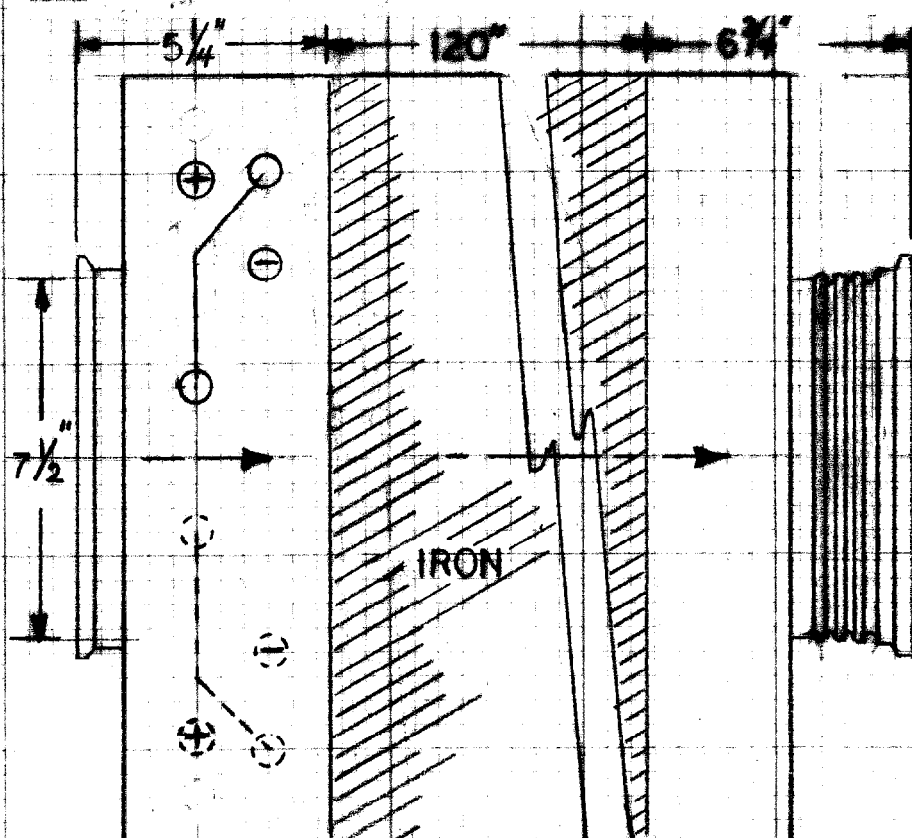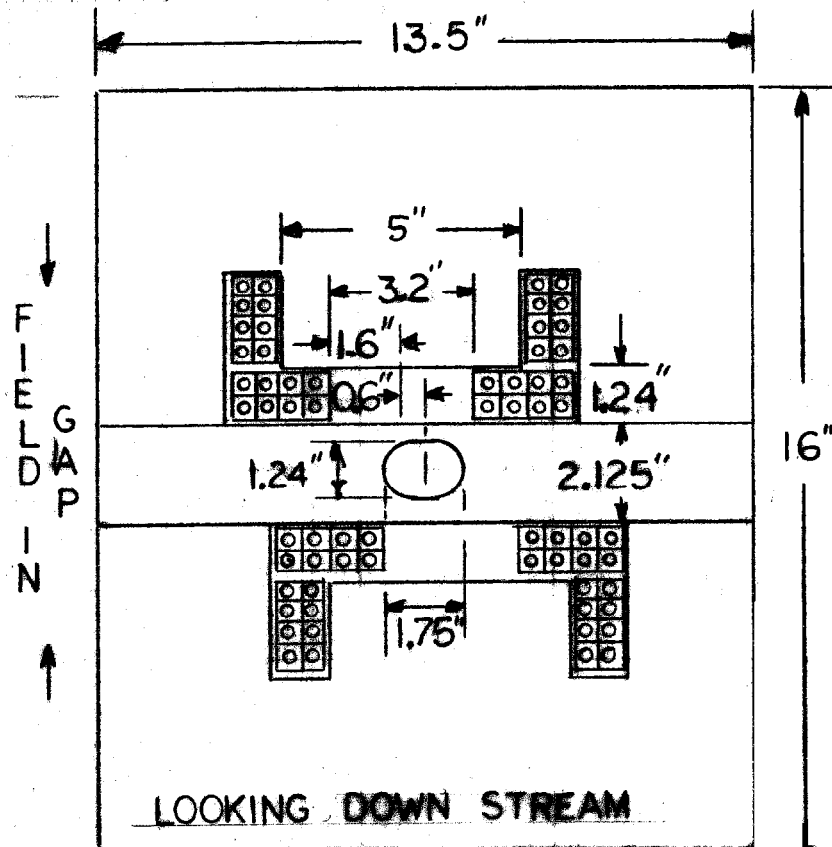$\theta_{mr} =$



LOOKING DOWN STREAM



IRON

Table II - Bend Angles, Currents, and Power for Enclosure "H"
        3-Way Split at 500 GeV

| Magnet | Name | No. Magnets | Bend Angle | B | Current | D.C. Power | Power Supply |
|--------|------|-------------|------------|---|---------|------------|--------------|
| Vertical Bend | MV320 | 3 | 8.568 mr | 14.8kG | 1066A | 600.kW * | 2 x 500kW transrex |
| East 3-Way | MH320E | 4 | 5.070 | 6.95 | 1089 | 91.1 | 240kW transrex |
| West 3-Way | MH320W | 4 | 5.070 | 6.95 | 1089 | 91.1 | 240kW transrex |
| East EPB dipoles | MH323 | 4 | 8.675 | 11.86 | 1145 | 83.9 | 500kW |
| Center EPB dipoles | MH322 | 2 | 4.635 | 12.67 | 1248 | 49.8 | 500kW |
| West EPB dipoles | MH321 | 9 | 24.526 | 14.91 | 1640 | 387.3 | 2 x 500kW |

If the peak energy of the machine were to be 450 GeV, the extra EPB dipoles in the
East and West line would not be necessary.  Parameters at 450 GeV would be:

| Magnet | Name | No. Magnets | Bend Angle | B | Current | D.C. Power |
|--------|------|-------------|------------|---|---------|------------|
| East EPB dipoles | MH323 | 3 | 8.675 mr | 14.23 kG | 1509A | 109.3kW |
| West EPB dipoles | MH321 | 8 | 24.526 | 15.09 | 1670 | 357.0 |

(*)   Assumes MV310 in series with MV320

Table III - Equipment Location in Enclosure "H". The distance along the beam
Z, is measured from the upstream wall of "H" to the upstream end of
the magnet, or face of SWIC box. The offsets are measured from the
present undeflected beam line entering Enclosure "H" (ref. print
0600 - LE - 24452). Positive offsets are to the East.

| Element | Beam Offset | Z | Element | Beam Offset | Z |
|---|---|---|---|---|---|
| Wall | -3.20" | 0 ft | | | |
| SWIC 318 | | 2.580 | MH323-1 | 4.17" | 200.145 ft |
| MV320-1 | -3.21 | 3.976 | -2 | 4.95 | 211.145 |
| MV320-2 | | 14.976 | -3 | 6.02 | 222.145 |
| MV320-3 | | 25.976 | -4 | 7.38 | 233.145 |
| SWIC319 | -3.33 | 37.080 | MVT323 | 9.02 | 244.145 |
| SWIC319E,C,W | | 38.559 | SWIC323 | | 249.145 |
| Shield or Col. | | 40.059 | Collimator | | 292.399 |
| MH320-1 | -3.37 | 46.281 | Wall | 18.24 | 301.524 |
| MH320-2 | | 57.281 | MVT322 | -4.14 | 261.149 |
| MH320-3 | | 68.281 | MH322-1 | -4.16 | 266.149 |
| MH320-4 | | 79.281 | MH322 2 | | 277.149 |
| SWIC320W,C,E | -3.53 | 90.385 | SWIC322 | | 288.649 |
| | | | Collimator | | 289.649 |
| MVT321 | | 195.729 | Wall | -5.51 | 301.439 |
| MH321-1 | -12.03 | 200.145 | | | |
| -2 | -12.91 | 211.145 | | | |
| -3 | -14.16 | 222.145 | | | |
| -4 | -15.77 | 233.145 | | | |
| -5 | -17.74 | 244.145 | | | |
| -6 | -20.06 | 255.145 | | | |
| -7 | -22.75 | 266.145 | | | |
| -8 | -25.80 | 277.145 | | | |
| -9 | -29.21 | 288.145 | | | |
| SC321 | -32.97 | 298.695 | | | |
| Wall | -33.86 | 301.480 | | | |

Beam Elevations, Inches Above 732' from Sea Level

| Place | P-West | P-Center | P-East |
|---|---|---|---|
| Upstream Wall | 9.264 | 7.752 | 6.238 |
| End MV320-3 | 11.427 | 9.855 | 8.282 |
| Downstream Wall | 12.194 | 10.207 | 8.331 |
| Slopes at MH320 | +0.260mr | +.122mr | -.015mr |

**SUBJECT**

2.28 x 5 x 120 Dipole (Modified B1)

**NAME**
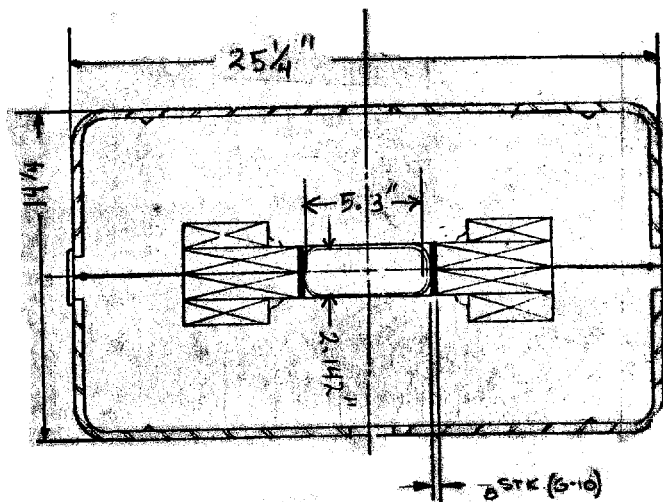C. S. Snowon/E. Tilles

**DATE**
5/22/74   **REVISION DATE**

## MAGNETIC FIELD

| | |
|---|---|
| CENTRAL FIELD | 16.0kG |
| GOOD FIELD | 4.6" x 1.75" |
| FIELD QUALITY | +0.14%,-0.06% |

**POWER:**

| | |
|---|---|
| Dc Power | 109.0kW |
| Current | 1116.0A |
| Voltage | 97.5V |
| Copper Temp. Ave. | |
| Resist @ Temp. | 0.0876$\Omega$ |
| Time Constant | 0.43sec |
| Inductance | 0.0375H |

## COOLING:

| | |
|---|---|
| Water Temp. Rise | 15°C |
| Total Flow | 9.6GPM |
| Pressure | 200 psi |

## COIL DATA:

| | |
|---|---|
| Conductor O.D. | 0.46" x 0.46" |
| Hole Diameter | 0.23" |
| Turns | 68 |
| Water Paths | 8 |
| Ave. Turn Length | 278" |

## WEIGHTS: (est.)

| | |
|---|---|
| Coil & Insul. | 1,170 lbs |
| Core | 10,300 lbs |
| Support | 200 lbs |
| Total Magnet Assembly | 11,670 lbs |

## CALCULATION CONSTANTS:

$B_{kg}$ =

$\theta_{mr}$ =
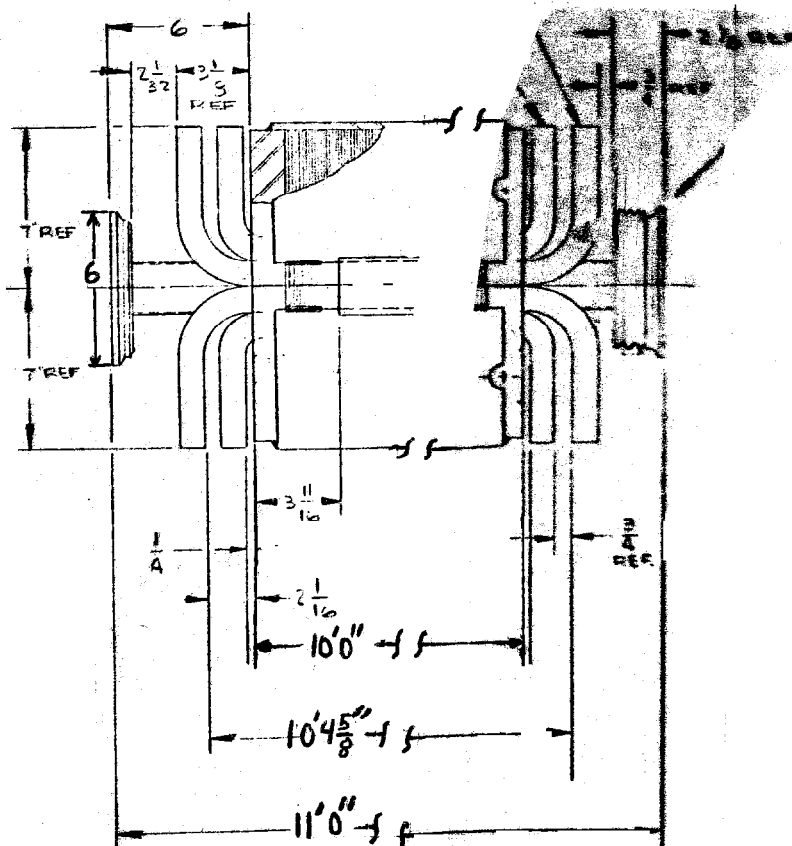
## Proton Department 3-Way split magnet

Average $\delta B/B$ as function of horizontal position
at upstream end of 4-magnet string. The average is
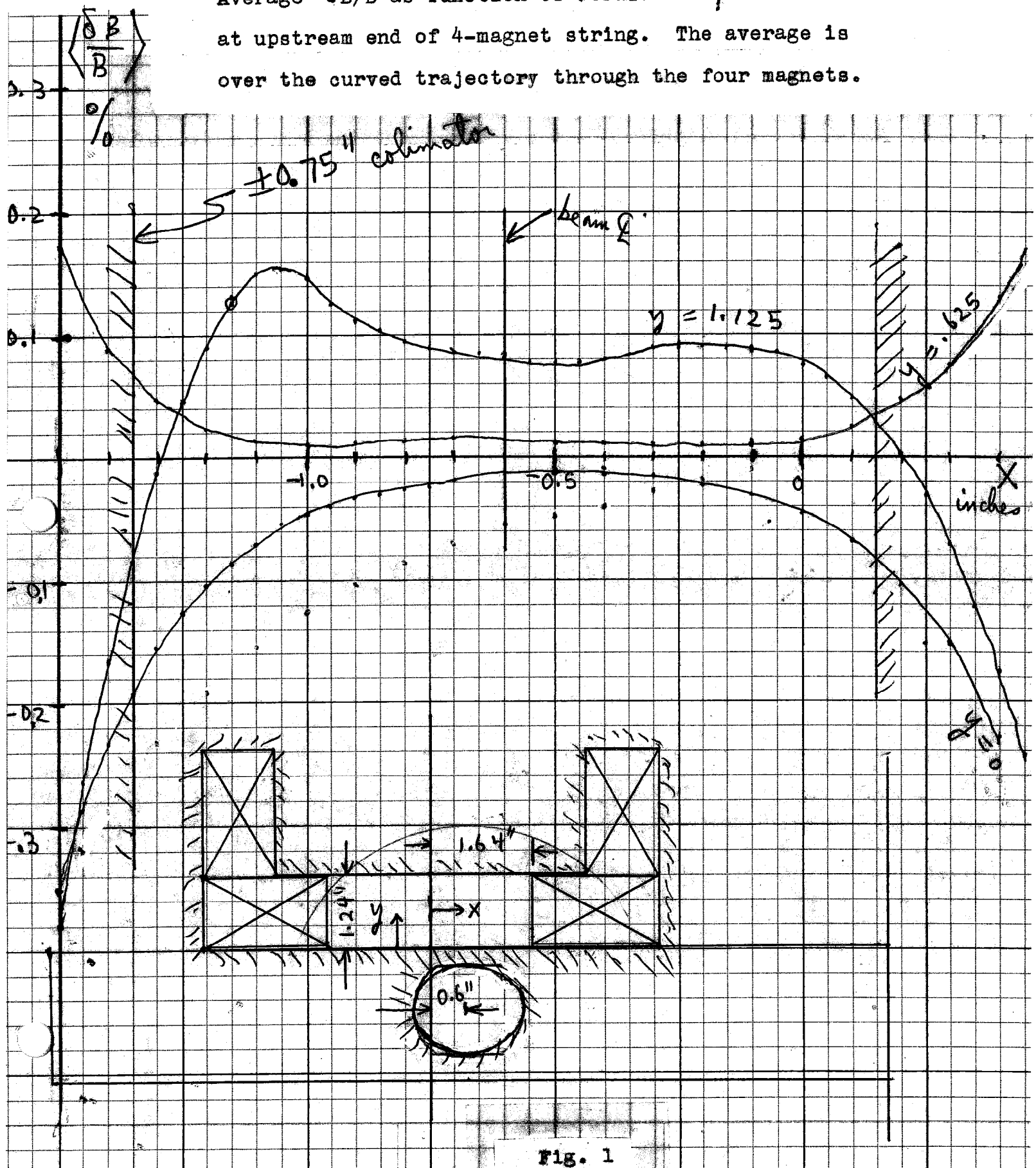over the curved trajectory through the four magnets.



Fig. 1

**Distortion of horizontal phase space due to worst field contour (y = 1.125") in Proton Department 3-Way Splitting Magnet.**
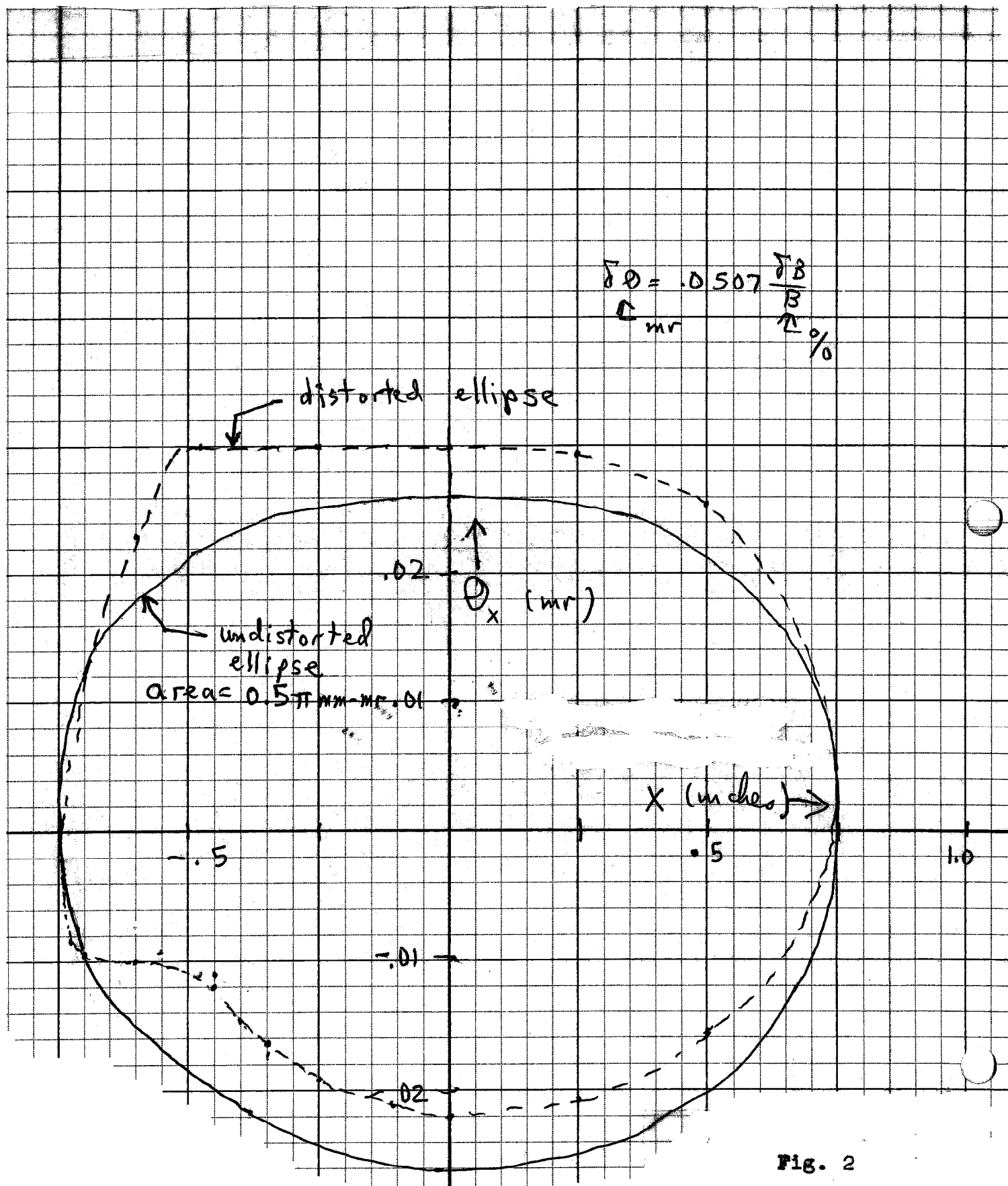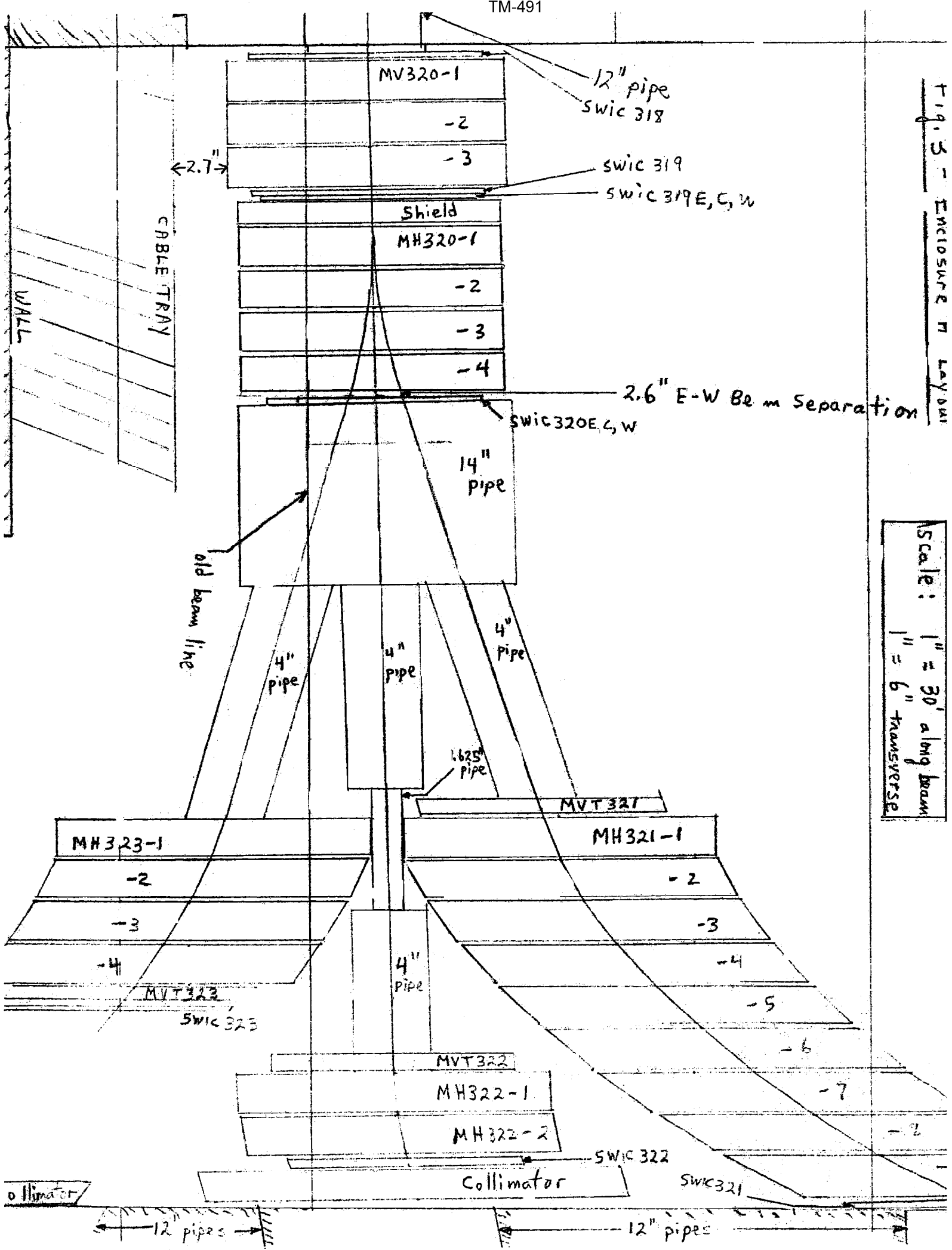


$$\delta\theta = .0507 \frac{\delta B}{B}$$
$$\theta_{mr} \qquad \%$$

distorted ellipse

undistorted ellipse
area = 0.5 π mm-mr

$\theta_x$ (mr)

.02

-.01

-.02

-.5

.5

1.0

X (inches)

Fig. 2

Fig. 5 - Enclosure M Layout

MV320-1
-2
-3
swic 318
12" pipe
swic 319
swic 319 E, C, W

←2.7"→

CABLE TRAY

WALL

Shield
MH320-1
-2
-3
-4

2.6" E-W Beam Separation
swic 320 E, C, W

14" pipe

old beam line

Scale: 1" = 30' along beam
1" = 6" transverse

4" pipe
4" pipe
4" pipe

.625" pipe

MVT 321
MH323-1
MH321-1
-2
-2
-3
-3
-4
-4
-5
MVT323
swic 323
-6
4" pipe
-7
MVT322
MH322-1
MH322-2
swic 322
Collimator
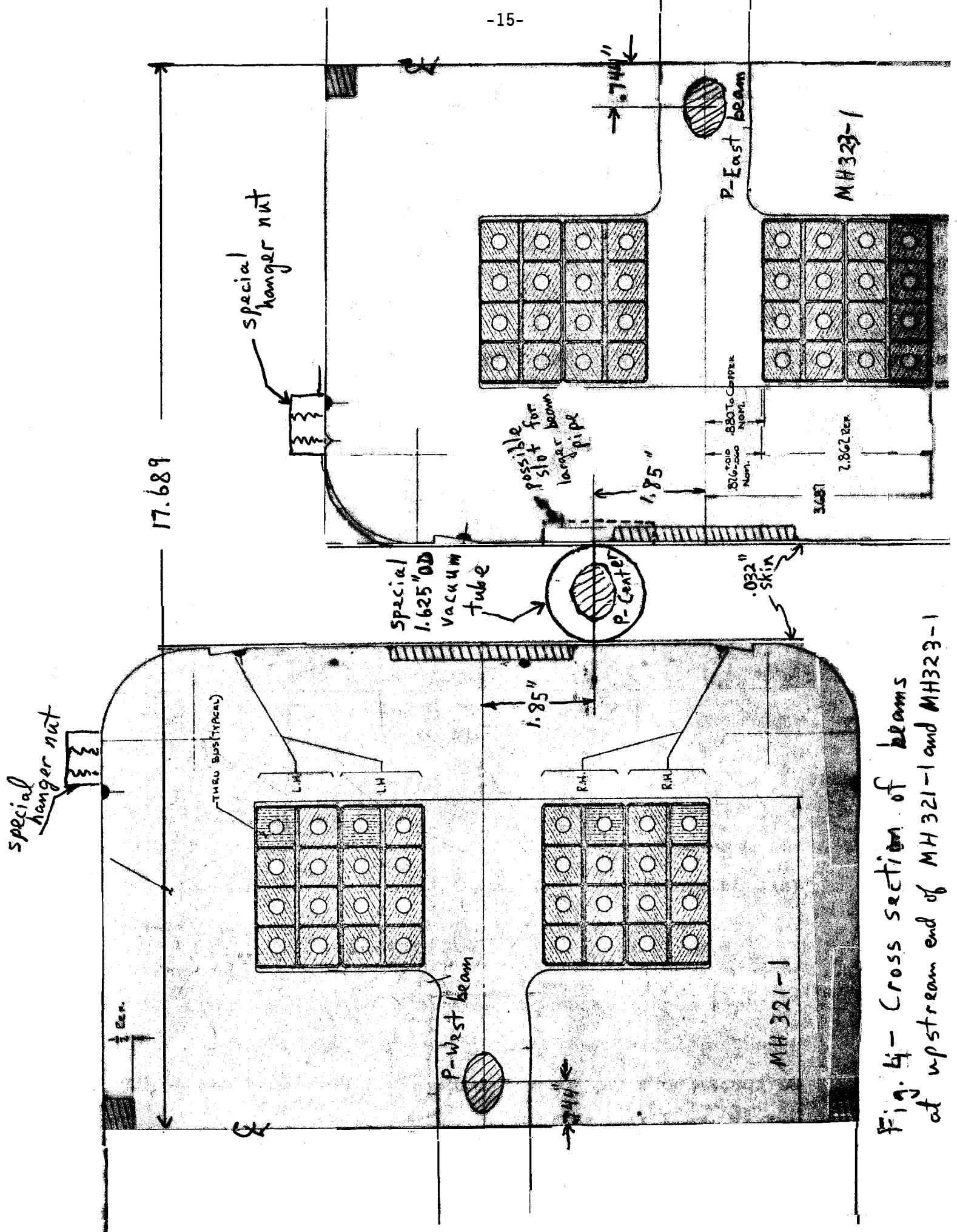swic 321
Collimator
←12" pipes→
←12" pipes→

Fig. 4- Cross section of beams
at upstream end of MH321-1 and MH323-1

# Field Uniformity of 2.28x5x120 Dipole (Modified B1)

B/B as a function of horizontal position in magnet, x, for three planes in the magnet.
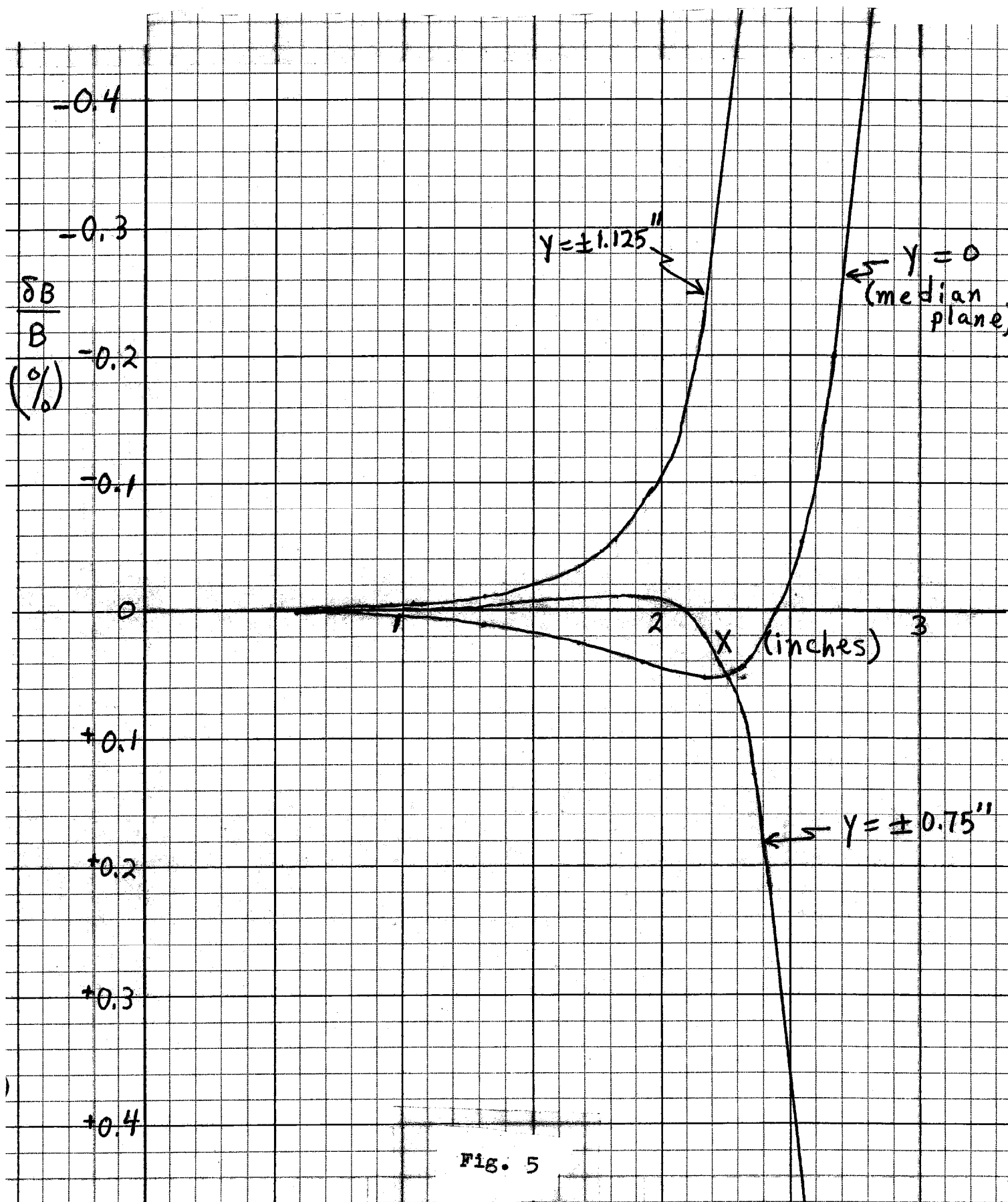


Fig. 5